DESIGN CONSIDERATIONS FOR THE REFLECTOR ANTENNA SYSTEM OF THE HIGH ALTITUDE MMIC SOUNDING RADIOMETER (HAMSR)

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***Abstract*—This paper describes some design aspects of the reflector antenna system for the High altitude MMIC sounding radiometer (HAMSR) on a remotely piloted aircraft. The goal of HAMSR project is to design, build, and demonstrate in the field, a miniaturized microwave atmospheric sounder implemented with Monolithic Microwave Integrated Circuit (MMIC) receiver modules and other solid state components. This passive microwave radiometer operating at millimeter wavelengths will make temperature soundings at oxygen emission lines at 53 and 118 GHz, and humidity sounding at water vapor emission line at 183 GHz. In this paper we will outline the design process and the analytic results for the three feed/reflector systems at the above three frequencies.**

1. INTRODUCTION

High altitude MMIC sounding radiometer (HAMSR) on a remotely piloted aircraft makes a radical departure in design from previous microwave sounders resulting in reductions in mass and power by an order of magnitude and reduction in cost by a significant factor from the current state of the art.

The goal of HAMSR project is to design, build, and demonstrate in the field a miniaturized microwave atmospheric sounder implemented with Monolithic Microwave Integrated Circuit (MMIC) receiver modules and other solid state components. This passive microwave radiometer operating at millimeter wavelengths will make temperature soundings at oxygen emission lines at 53 and 118 GHz, and humidity sounding at water vapor emission line at 183 GHz.

Previous humidity and temperature soundings have mainly been done at 22.2 and 54 GHz, which require relatively large and heavy hardware. The instrument is required to have a temperature sounding accuracy of 2 degrees Kelvin and a humidity sounding accuracy of 20%. It will have a vertical resolution of 2 km in the troposphere and a horizontal resolution of 2 km. HAMSR instrument is intended primarily as a tropospheric sounder but is configurable to make other types of measurements.

This project will demonstrate the maturity of the MMIC technology and the mass, cost, power, and cost benefits of a miniaturized MMIC-based sounding system. It will verify the scientific validity and effectiveness of temperature soundings at 118 vs. 54 GHz soundings. In addition, it will demonstrate the operational capabilities of a UAV-based sounder.

The HAMSR instrument is designed to be flown aboard solar powered UAVs being developed under the NASA Environmental Research Aircraft and Sensor Technology (ERAST) program.

One of the main features of HAMSR is an optics module composed of reflector antennas, calibrators, scanners, and diplexers, which can be easily modified to satisfy specific spatial sampling and coverage requirements.
In this paper we will outline the design process and the analysis results for the feed/reflector systems as well as the diplexer or dichroic plate. Fabrication and test results for the various components of the system will be presented in a future paper.

2. Optical Prescription

As shown in Figure 1, three offset-fed parabolic reflector systems are designed for operation at 54, 118, and 183 GHz. They are arranged in the following way. The 55 GHz reflector takes direct input radiation from Earth, while the input radiation is directed to the 118 and 183 GHz reflectors via a flat plate reflector and a frequency selective surface (FSS) or dichroic plate. The RF specifications for the antenna systems are summarized as follows.

Frequencies

The HAMSR optics system will operate in three bands centered at 55 (49.4-56.9), 118 (112.5-125.0) and 183 (162.0-194.8) GHz.

Beamwidth

The HPFW beamwidth will be 5.7 degrees ± 10% at all frequencies.

Polarization

Polarization shall be linear and in the scan plan of the antenna system. At nadir pointing the polarization of all three beams shall be in the same direction.

Cross-Polarization

The ratio of the integrated cross-polarized power within the 14.3 degrees (2.5 x HPFW beamwidth) to the co-polarized power shall be less than 17 dB for all three beams at the nadir pointing position.

Beam Efficiency

The integrated main beam energy, within 14.3 degree from beam center, shall be greater than 95% of the total integrated energy.

The reflector beam patterns must have very low sidelobes (less than 30 dB) to obtain the required high beam efficiency, which mandates high ly tapered reflector aperture illumination and stringent surface accuracy and alignment requirements. Corrugated circular feedhorns are used to receive the radiation.

As shown in Figure 1, the 55 GHz reflector and the flat plate mirror rotate around a single axis of revolution in order to provide the nadir coverage in +/- 55° range. In each revolution the reflectors will be exposed to hot and cold targets for the purpose of calibration. A three dimensional overall view of the optical bench and a more close-up view of the reflectors and the hot and cold targets, as generated by the Mechanical Desktop, are shown in Figures 2 and 3.

3. Design Procedure

Full wave mode-matching technique is used to analyze and design the feed horns, while the reflector analysis and design is based on the physical optics theory.

The analysis of the oblique incidence on the dichroic plate is based on method of moments with floquet harmonics expansion in the free space and waveguide modal expansion in the aperture and interface matching.

The analysis of the oblique incidence on the dichroic plate is based on method of moments in conjunction with Floquet harmonics theory. Computer programs used in the analysis are based on the codes developed at JPL for the analysis of the reflector systems, corrugated horns, waveguide junctions, and frequency selective surfaces [1-3]. Also utilized were the modified forms of codes in [4-6]. Additional programs for geometrical layout of the feed horns and reflectors and plotting of the various field quantities were developed in MATLAB language.

4. THEORETICAL ANALYSIS

Feed horns

All three reflectors use circular corrugated horns and include a matching/transition section from circular to rectangular waveguide. Corrugated feed horns were used to equalized the E and H plane field patterns. Approximate length and dimensions of the feed horns including the distance from aperture to the receiver flange, which comprises the horn length and the circular /rectangular transition region, are given in the following table. For brevity, the geometry of the corrugations are not presented in this paper, but will be presented in a future paper.

Patterns of the circular corrugated horns are produced based on the modal expansion in the horn and are presented in the next section.

Table 1. **Geometrical parameters of the feed horns**

Freq.	Rectangular guide	Circular guide Diameter	Horn aperture	Total length
55 GHz	WR 19 (40-60 GHz) In: 0.188” x 0.094” Out:0.268” x 0.174”	0.22” 5.6 mm	17.3 mm	35.7 mm
118 GHz	WR 8 (90-140 GHz) In: 0.08” x 0.04” Out:0.156” diameter	0.1” 2.6 mm	7.6 mm	15.6 mm
183 GHz	WR 4 (170-260 GHz) In: 0.043” x 0.215” Out:0.156” diameter	0.06” 1.5 mm	5.3 mm	11.4 mm

Reflectors

The reflector patterna are obtained using the calculated near field patterns of the feed horns. Due to the high offset in the 55 and 183 GHz reflector systems, the cross pol is relatively high but still acceptable (< 17 dB). A trade-off was conducted to obtain the best illumination taper and corresponding reflector far field patterns.

An optimized set of parameters and corresponding figures are presented for the 16 dB reflector edge taper which is equalized at the two edges. The feed aperture has been moved toward the reflector from the focal point in order to make the patterns as circularly symmetric as possible. Figures 4(a,b,c), 5(a,b,c), and 6(a,b,c) present the geometry, feed pattern and reflector far field patterns at the 55, 118, and 183 GHz frequencies, respectively.

Dichroic plate

The FSS or dichroic plate is a high pass filter designed to transmit the 183 GHz signal while reflecting the 118 GHz signal, both incident at 22.5 degrees from normal. The geometry of a segment of the plate is shown in Figure 7. The computed reflection and transmission response of the plate is given in Figure 8. This is a design very sensitive to dimensional tolerances, which must be maintained within a fraction of a mil.

5. Conclusions and Future Plans

In this paper we have presented some of the design parameters and theoretical analysis results for the optics of the HAMSR radiometer. All the components of the optics have been fabricated based on the above results and are presently under test.

ACKNOWLEDGMENT

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REFERENCES

[1] R. E. Hodges, W. A. Imbriale, "Computer Program POMESH for Diffraction Analysis of Reflector Antenna," Internal Report, Jet Propulsion Laboratory, February 1992.

[2] D. Hoppe, "Scattering Matrix Program for Circular Waveguide Junctions," Internal Report, Jet Propulsion Laboratory, October 1984.

[3] J. C. Chen, "Analysis of a Thick Dichroic Plate with Rectangular Holes at Arbitrary Angles of Incidence," TDA Progress Report 42-104, Jet Propulsion Laboratory, Pasadena, California, pp. 110-134, February 15, 1991.

[4] C. C. Chen, "Transmission of Microwave Through Perforated Flat Plates of Finite Thickness," IEEE Trans. Microwave Theory Tech., vol. MTT-21, pp. 1-6, January 1973.

[5] P.J.B. Clarricoats and A.D. Olver, "Corrugated horns for microwaveantennas," London, UK: P. Peregrinus on behalf of the Institution of Electrical Engineers, 1984.

[6] Leo Diaz, Thomas Milligan, *Antenna Engineering Using Physical Optics,* Boston: Artech House, 1996.

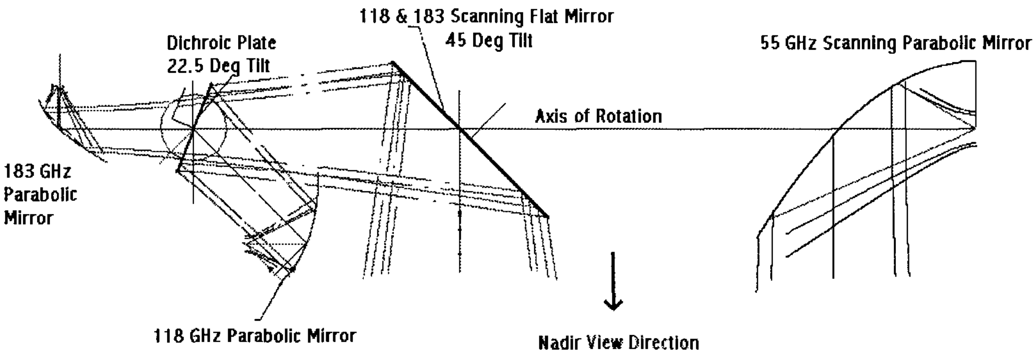

Figure 1. **Schematic configuration of the three reflector antenna systems**

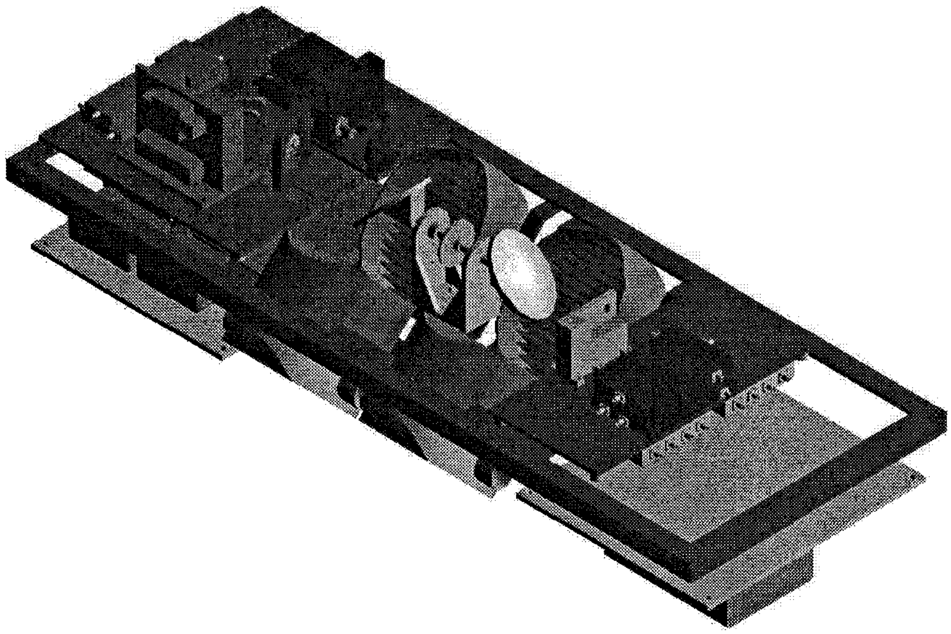

Figure 2. **A Mechanical Desktop view of the overall system optics**

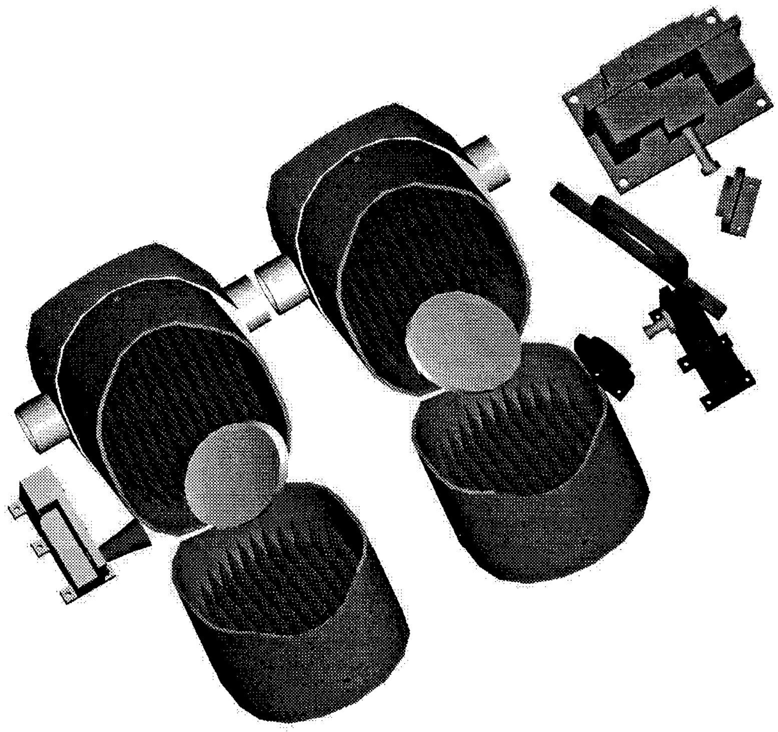

Figure 3. **A Mechanical Desktop layout of the reflector antenna components.**

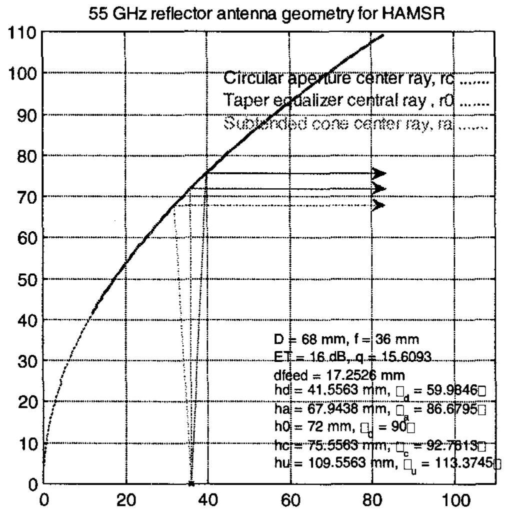

Figure 4(a). **Reflector geometry for 55 GHz operation**

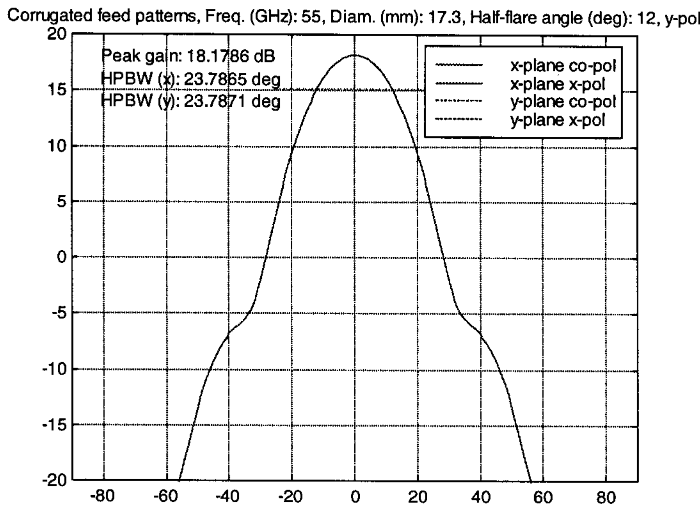

Figure 4(b). **55 GHz Feed pattern**

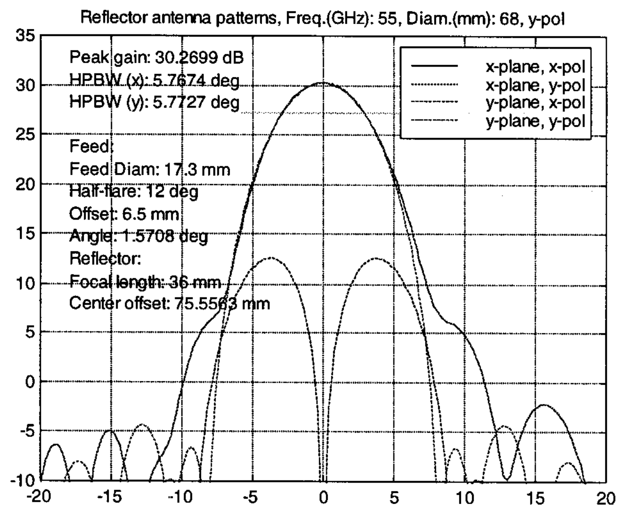

Figure 4(c). **55 GHz Reflector pattern**

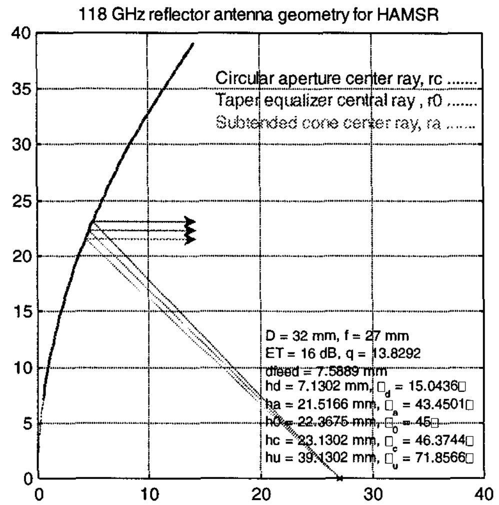

Figure 5(a). **Reflector Geometry for 118 GHz operation**

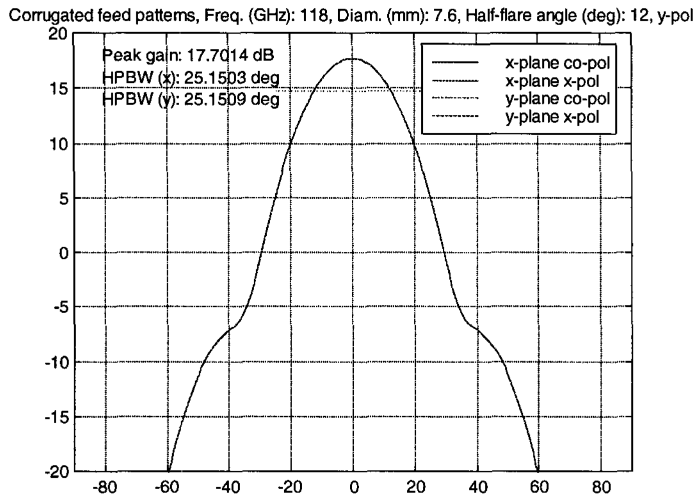

Figure 5(b). **118 GHz Feed pattern**

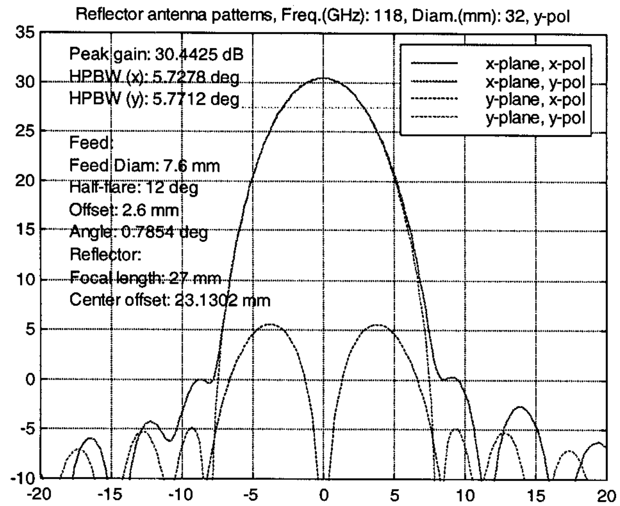

Figure 5(c). **118 GHz Reflector pattern**

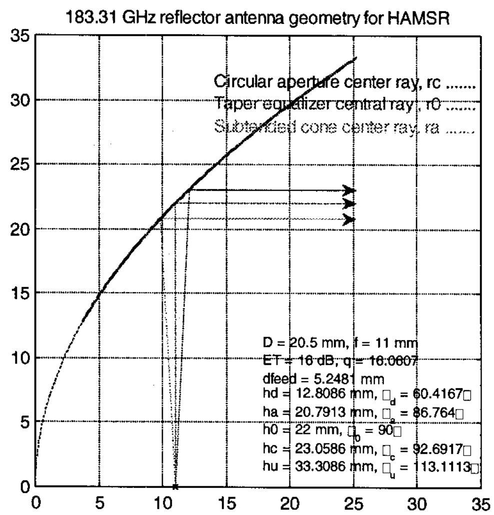

Figure 6(a). **Reflector geometry for 183 GHz operation**

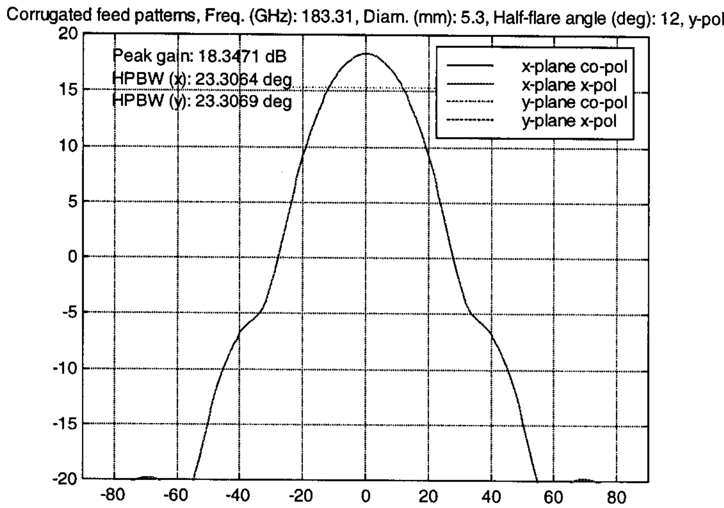

Figure 6(b). **183 GHz Feed pattern**

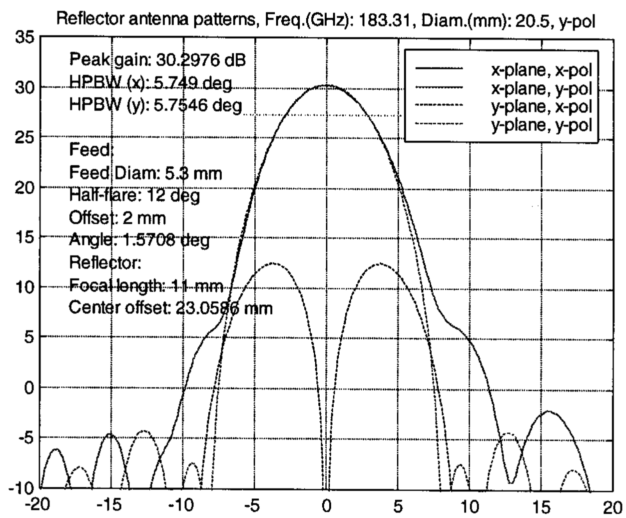

Figure 6(c). **183 GHz Reflector pattern**

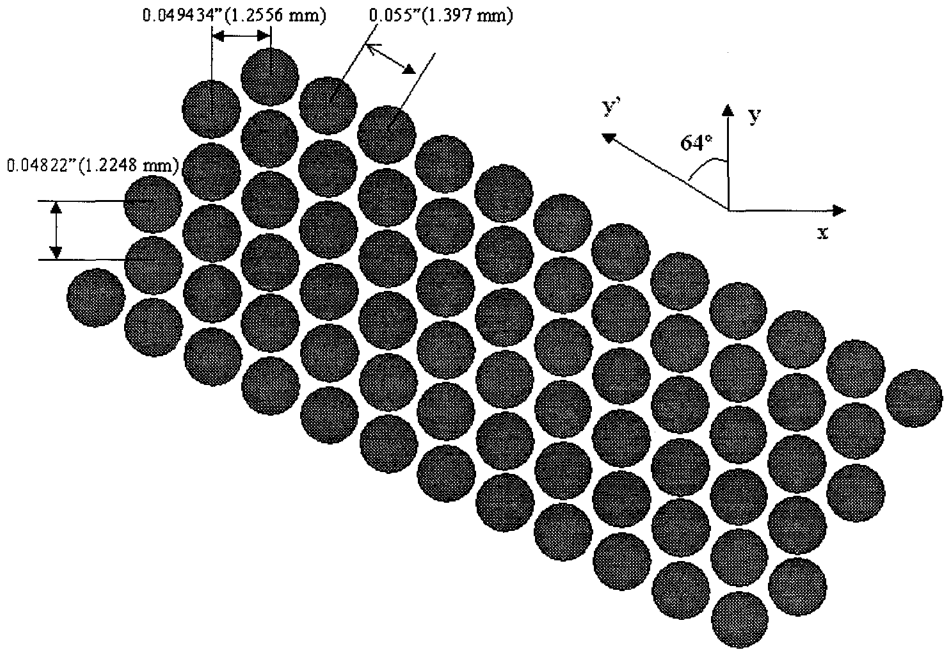

Figure 7. **Geometrical configuration of a sample segment of the dichroic**

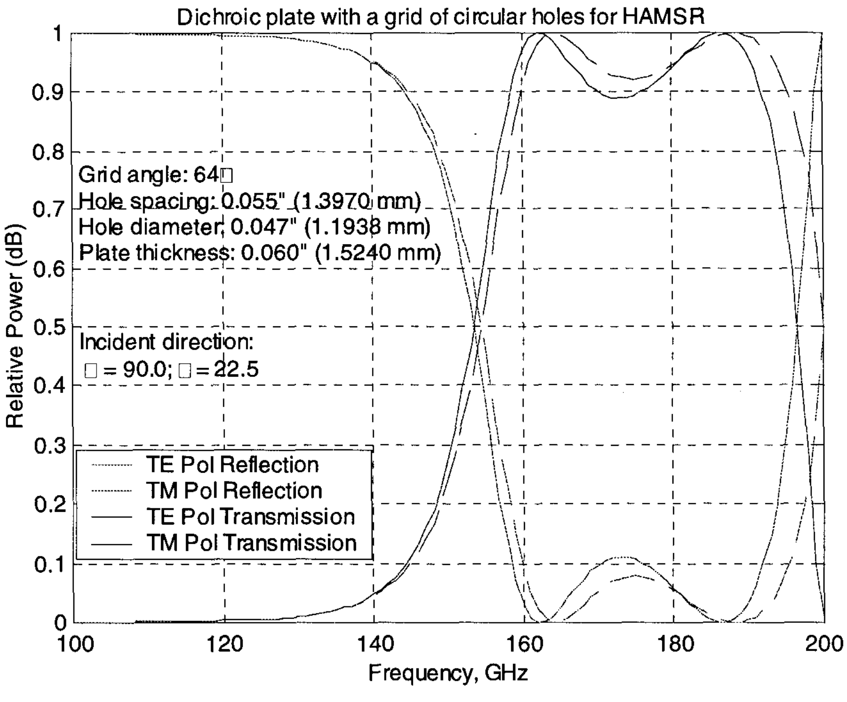

Figure 8. **Computed transmission & reflection characteristics of dichroic plate.**